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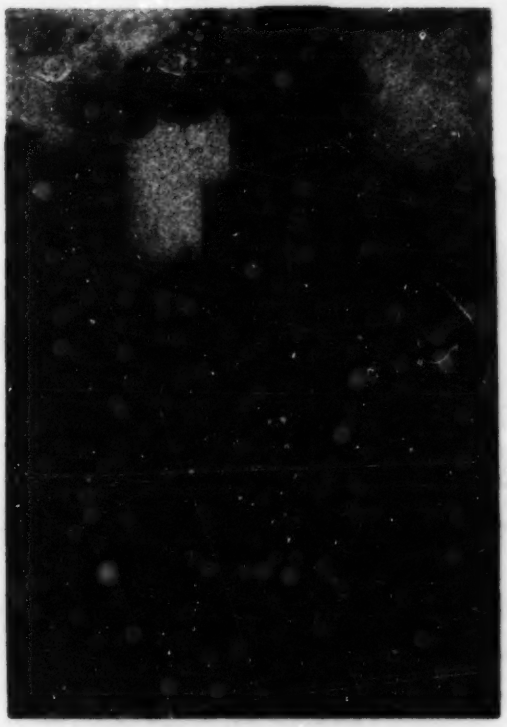

DIRECT CONTACT FLUE GAS HEAT RECUPERATOR

CANADA PACKERS INC.
WINNIPEG PACKING HOUSE

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MANITOBA/CANADA CONSERVATION AND RENEWABLE ENERGY DEMONSTRATION AGREEMENT

The availability of secure and affordable energy supplies is a subject of national concern. It is an accepted fact that our primary energy sources - oil and natural gas - are becoming less accessible and more costly. However, Canada is well-endowed with non-renewable and alternative resources that can provide a bridge into the future.

To this end, the governments of Manitoba and Canada have entered into a Conservation and Renewable Energy Demonstration Agreement which was signed May 9, 1980 and terminates March 31, 1984. The Agreement is dedicated to the development and demonstration of conservation and renewable energy technologies. Equally cost-shared by the provincial and federal governments, the program has a total budget of $18-million.

The objectives of CREDA are:

- To develop and demonstrate promising new technologies, which, when widely adopted, will exploit renewable resources, conserve energy and/or use energy more efficiently.
- To develop broad public awareness of the potential of renewable energy and conservation technology.
- To provide opportunities for the commercial application of the technologies within Manitoba.
- To create economic spin-off benefits for manufacturing, industry and commerce.
- To create employment in new or existing energy-related industries.

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1.0 EXECUTIVE SUMMARY

Under the Canada/Manitoba Conservation and Renewable Energy Demonstration Agreement (CREDA), Canada Packers Inc. received funding to offset a portion of the capital costs for a novel boiler flue gas heat recovery system. This system, referred to as a "Direct Contact Heat Recuperator", was designed and manufactured by John Thurley Ltd. and was installed at Canada Packers' Winnipeg Packinghouse plant.

In contrast to conventional heat recovery systems, such as economizers and combustion air preheaters, the heat recuperator is capable of recovering up to four times more of the available waste heat from the flue gases. This is due to its ability to recover both the latent heat, by condensing the flue gas water vapour, and a greater portion of the sensible heat. As a result, the exit flue gas temperature is reduced to about 30°C.

Flue gas heat recuperators are ideally suited to operations which can make use of large quantities of hot water. Most food processing plants fall into this category. At Winnipeg Packinghouse, the recovered heat is transferred indirectly to the potable hot water heating system using a plate heat exchanger.

This report details the performance of Winnipeg's recuperator during its first six months of operation. The monitoring results have shown that the average overall combustion efficiency of the boiler system has been raised from 81.8 percent to 92.2 percent. This improvement will result in an estimated annual fuel savings of 1,100,000 cubic metres of natural gas, a net cost reduction of $141,000.

During the six month monitoring period, the recuperator was in operation an average of 86.2 percent of the time. In the first two months, winter conditions created freeze-up problems with the bypass damper. Thus, the initial utilization was about 60 percent. After this problem was solved, the utilization rate rose to its present level of over 95 percent.

Overall, this project is considered to be very successful, both technically and financially. It is expected that the planned savings will be achieved.

RÉSUMÉ ADMINISTRATIF

En vertu de l'Entente Canada-Manitoba de démonstration des énergies renouvelables et des économies d'énergie (DEREE), la Canada Packers Inc. a bénéficié d'une subvention lui permettant d'amortir partiellement le coût d'installation d'un nouveau système de chaudière à récupération de la chaleur des gaz de combustion. Appelé "récupérateur de chaleur à contact direct", ce système a été conçu et manufacturé par la compagnie John Turley Ltd. qui se chargea de l'installer dans la fabrique de conserves de la Canada Packers à Winnipeg.

À l'encontre des systèmes ordinaires de récupération de chaleur comme les économiseurs et les appareils de chauffage d'air par combustion, le récupérateur de chaleur est capable de récupérer quatre fois plus de chaleur provenant des gaz de combustion. Cela est dû à la double propriété de pouvoir récupérer la chaleur latente par condensation de la vapeur d'eau et de pouvoir utiliser une plus grande partie de la chaleur manifeste. Par suite, la température des gaz de combustion à la sortie est réduite à 30° C.

Les récupérateurs de chaleur peuvent être utilisés de manière idéale lorsque de grosses quantités d'eau chaude sont disponibles. C'est le cas de la plupart des manufactures de produits alimentaires. Dans l'usine winnipégoise de la Canada Packers, la chaleur récupérée est transférée indirectement au système de chauffage d'eau potable au moyen d'un échangeur thermique à plaque chauffante.

Vous trouverez dans ce rapport, les détails du rendement du récupérateur au cours des six premiers mois de fonctionnement. En ce qui concerne la chaudière, les résultats de contrôle ont fait ressortir que le rendement moyen de combustion est passé dans l'ensemble de 81,8 % à 92,2 %. Grâce à cette amélioration, la consommation annuelle de gaz naturel sera réduite, estime-t-on, de 1 100 000 mètres cubes, soit une économie de 141 000 $.

Pendant la période de contrôle de six mois, le récupérateur ne fonctionnait en moyenne que 86,2 % du temps. Par suite du climat hivernal des deux premiers mois, le gel causa des problèmes dans les régulateurs des gaz. Au début, la durée d'utilisation ne fut donc que 60 %. Mais une fois ce problème résolu, le taux d'utilisation atteignit sa valeur actuelle, c'est-à-dire plus de 95 %.

Dans l'ensemble, ce projet a été couronné de succès, tant du point de vue technique que du côté financier. Selon nos prévisions, les objectifs d'économie seront atteints.

2.0 INTRODUCTION

In the summer of 1982, Canada Packers Inc. installed a Direct Contact Heat Recuperator to recover waste heat from the boilers at its Winnipeg Packinghouse plant. The unit was designed by John Thurley Ltd. of Harrogate, England, and components were manufactured in Canada. Installation was carried out by Winnipeg's Engineering Department under the direction of Mr. J. Magro.

The heat recuperator can recover up to four times the heat recovered by conventional heat recovery systems. This is primarily due to its ability to condense the water vapour in the flue gas, thereby releasing its latent heat of vapourization. Also, the sensible heat recovery is greater than that of conventional systems. The flue gas exits the recuperator at temperatures as low as 30°C.

Basically, the recuperator is a heat exchanger that transfers heat from the flue gas by means of direct contact with water sprays. The heated water is then collected and pumped through a plate heat exchanger which transfers the heat to plant process water.

The $400,275 cost of the project was partially offset by a $180,592 contribution from the Manitoba/Canada Conservation and Renewable Energy Demonstration program.

3.0 BACKGROUND

Until recently, the amount of heat that could be recovered from a boiler's flue gases was limited by the requirement that they not be cooled below about 150°C in order to prevent condensation of water vapour and various acidic compounds. This was done to prevent corrosion problems from occuring in the boiler's breeching and stack as well as the heat recovery equipment.

The potential fuel cost savings from recovering more of the waste heat were not sufficient to justify the extra cost for larger heat transfer surfaces and more extensive use of corrosion resistant materials.

3.1 CONVENTIONAL FLUE GAS HEAT RECOVERY SYSTEMS

Conventional flue gas heat recovery systems are either economizers or combustion air preheaters.

An economizer is an air-to-liquid heat exchanger used to preheat boiler feedwater. It usually consists of an arrangement of finned tubes located in the boiler's stack, through which the feedwater flows.

In order to prevent corrosion problems due to condensation of water vapour and acids, the flue gas temperature must be maintained above 150°C. Feedwater provides a simple answer to this consideration since it normally enters the economizer at a temperature above 100°C, which is sufficient to maintain the external surface temperature of the heat exchange tubes above 150°C. This simple control scheme depends on maintaining a balance between the flue gas and feedwater flow rates. During periods of low boiler firing rate, the flue gas flow rate drops, causing an imbalance which results in a decrease in the flue gas temperature leaving the economizer. In order to prevent the temperature from dropping below the condensation point,

3.1 CONVENTIONAL FLUE GAS HEAT RECOVERY SYSTEMS (continued)

automatic systems can be installed to bypass the economizer or to raise the temperature of the feedwater entering the economizer.

A combustion air preheater is an air to air heat exchanger. It saves fuel by preheating the air used to sustain combustion.

One type of air preheater is called a recuperator. It usually consists of a plate heat exchanger with the flue gas and combustion air flowing on opposite sides of the plate. Another type of preheater, called a regenerator, transfers heat by alternately exposing a thermal storage mass to the flue gas and the combustion air. A very common type of regenerator is the heat wheel. It consists of a rotating mass, half of which is in the flue gas stream while the other is in the combustion air stream.

In order to prevent condensation, proper sizing of an air preheater is necessary. At low firing rates it may be necessary to bypass the preheater in order to maintain the flue gas temperature above 150°C.

Although they have some limitations, economizers and air preheaters have proven to be very practical devices over many years. They can improve the overall boiler combustion efficiency to as much as 85 percent.

TABLE I

PERFORMANCE OF CONVENTIONAL vs. CONDENSING HEAT RECOVERY SYSTEMS

Heat Recovery System	Exit Flue Gas Temperature	Overall Combustion Efficiency (1)	Heat Recovery Rate (2)	
			% Fuel Input	% Waste Heat
None	238°C	80.0%	0.0	0.0
Conventional	150°C	84.1%	4.1	20.5
Condensing	30°C	96.3%	16.3	81.5

(1) Assuming 25 present excess air.

(2) Assuming no losses in heat recovery system.

3.2 CONDENSING HEAT RECOVERY SYSTEMS

Today's high fuel prices have prompted several companies to address the potential to economically recover more of the heat from boiler flue gases. This has resulted in the development of condensing heat recovery systems, which are capable of recovering up to four times as much heat as conventional economizers and air preheaters. This vast improvement in performance has been achieved as follows. First, most of the sensible heat is recovered from the flue gases by cooling them to an exit temperature of 30°C or less. This low flue gas temperature in turn causes the water vapour to condense from the flue gas and release its latent heat of vapourization which can then also be recovered.

Table I shows an example of the potential improvement in performance of condensing heat recovery systems compared with conventional systems. The condensing system can recover nearly four times as much heat as the conventional system. This improves the overall combustion efficiency to 96.3 percent compared to 84.1 percent with a conventional system.

Although they can recover much more heat than conventional systems, condensing heat recovery systems are also much more costly. There are several reasons for this. Condensing systems tend to be physically larger than conventional systems in order to provide extra heat transfer surface. They also require the extensive use of corrosion resistant materials due to the condensing of acidic compounds with the water vapour. Finally, condensing systems can be more complex than conventional systems, requiring auxiliary equipment such as pumps and fans and more sophisticated controls.

Whether or not the extra cost of a condensing heat recovery system can be justified, depends largely on the price of fuel, which varies widely across Canada. Therefore each potential installation should be evaluated separately.

3.3 APPLICATION OF CONDENSING HEAT RECOVERY AT THE WINNIPEG PACKINGHOUSE

In 1981, various flue gas heat recovery systems were considered for the three boilers at the Winnipeg packinghouse plant. Among them were condensing heat recovery systems designed to preheat water for use in processing and sanitation as well as for boiler feed. A study of the plant's daily and seasonal steam and hot water production profile confirmed that the cost of recovering the additional heat could be justified.

A condensing heat recovery system designed and manufactured by John Thurley Ltd., and called a Direct Contact Heat Recuperator was selected. Due to the technical risks associated with applying new technology, and the longer payback period for the recuperator compared to an economizer, a proposal was made to demonstrate the technology under the Manitoba/Canada Conservation and Renewable Demonstration Program. This proposal was approved in the fall of 1981.

The Direct Contact Heat Recuperator was installed during the summer of 1982. The remainder of this report documents the first six months' performance of the unit.

4.0 DIRECT CONTACT HEAT RECUPERATOR

In the summer of 1982, a heat recuperator designed and manufactured by John Thurley Ltd., was installed at the Winnipeg Packinghouse plant. This system recovers waste heat from the flue gases of the three steam boilers.

4.1 PRINCIPLE OF OPERATION

The Thurley recuperator recovers heat from flue gases by bringing them into direct contact with cold water sprays. The cold sprays are essential to achieving the recuperator's high rate of heat recovery. They cause the water vapour in the flue gas to condense, thereby releasing its latent heat of vapourization to the water spray. The latent heat provides approximately half of the heat recovered by the recuperator. The remainder is due to sensible heat transfer.

The recuperator produces water at a temperature of approximately 54°C. The water is passed through a plate heat exchanger to heat potable process water. The flue gases leave the recuperator at a temperature of 38°C or less, thereby raising the overall combustion efficiency to in excess of
96 percent.

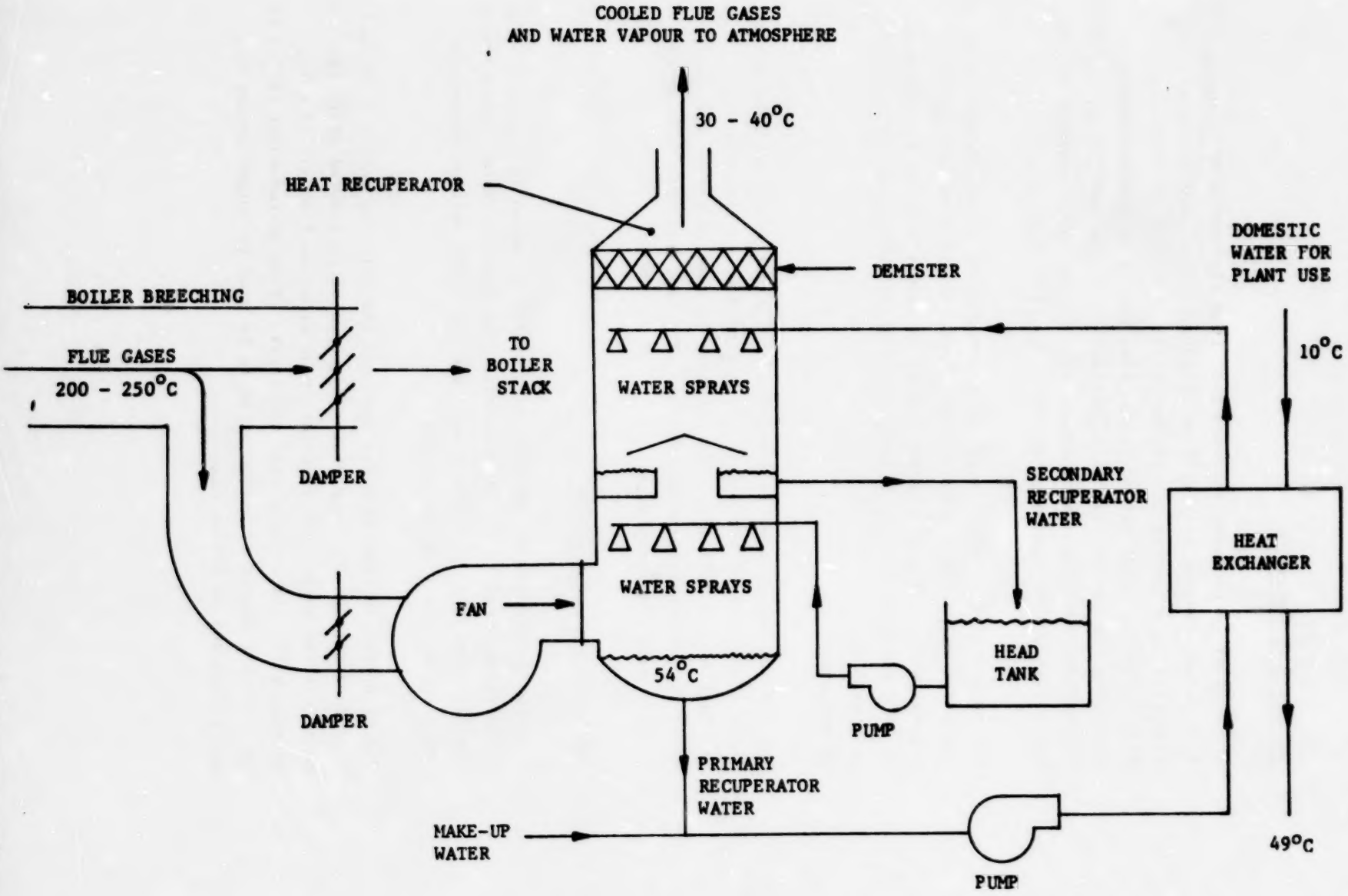
The Thurley recuperator is ideal for operations which can make use of large quantities of hot water. Many companies in the Food and Beverage sector fall into this category because of their need for hot water for processing and sanitation. The heat can also be used to preheat boiler make-up water.

4.2 DESCRIPTION OF RECUPERATOR

A schematic diagram of the heat recuperator is shown in Figure 1. The recuperator consists of two sections. The lower section, incorporates the flue gas inlet and quench zone and the upper section houses the demister and the flue gas outlet.

During operation, the flue gas bypasses the existing boiler stack and is forced through the recuperator by means of an induced draft fan. A recirculating water loop transfers heat from the flue gas to cold, potable water via a plate heat exchanger. This heated water (49°C) is then further heated with live steam to be used for plant processes, sanitation and as boiler make-up.

FIG. 1. THURLEY DIRECT CONTACT RECUPERATOR



4.2 DESCRIPTION OF RECUPERATOR (continued)

Recirculating water cooled in the plate heat exchanger is sprayed into the upper contact section of the recuperator and collected on a stainless steel baffle plate. This partially heated water is then run off to a head tank, from which it is pumped to the sprays of the lower quench section. After collection in the base of the recuperator it is then pumped back to the plate heat exchanger, which completes the loop.

Direct contact with acidic compounds in the flue gas causes the recirculating water to become acidic. Furthermore, recirculation causes the acids to concentrate, thereby continuously reducing the pH. This effect is partially countered by adding make-up water at the head tank to dilute the acid, and maintain the pH above 4. This minimizes the acidity but does not eliminate it, therefore corrosion resistant materials have been used throughout the recuperator. Stainless steel has been used in the components located in the lower section, which have the most contact with the recirculating water. The stack and flue gas outlet have been con- structed of fibreglass reinforced plastic.

The recirculating water flow rate can be manually or automatically controlled in order to maintain a maximum temperature of 54°C in the base of the recuperator. To maintain efficient spray contact action and quenching, the water flow rate is maintained above a minimum allowable level. Thus, under conditions of reduced boiler load, a lower recirculating water temperature will result, but the heat recovery efficiency will, however, be maintained.

5.0 HEAT RECUPERATOR PERFORMANCE

5.1 RECUPERATOR UTILIZATION

In order to maximize the savings, it is necessary to maximize the utilization (operating hours) of the recuperator.

Each shift, the stationary engineer reads an elapsed time meter and records the number of recuperator operating hours, along with the reasons for any down-time. This information has been valuable to the project engineer in identifying and solving problems.

The utilization rate is shown in Table 2. It has been expressed in hours per week and as a percent of the maximum possible hours (168). The table shows that the utilization rate averaged 86.4% during the monitoring period. The utilization rate averaged a rather low 60% during the first seven weeks of the monitoring period. This was largely due to frozen damper air control lines (section 4.3.1). When that problem was solved, the utilization improved to its present rate, in excess of 95%.

5.2 HEAT RECOVERY RATE

The amount of heat recovered is measured by a meter which records the heat transferred from the recuperator water to the plant water in the plate heat exchanger. This data is used to calculate the heat recovery as an hourly rate and as a percentage of the boiler fuel input, as shown in Table 2. The latter figure is a good indicator of the recuperator's heat recovery performance.

Table 2 shows that during the monitoring period, the heat recovery rate averaged 4.38 GJ/h. This is equivalent to 10.4% of the boiler fuel consumption. Effectively, the overall combustion efficiency has been improved by 10.4%, from 81.8% to 92.2%.

The heat recovery efficiency of the recuperator averages approximately 70%, which is considered to be good performance for any heat recovery system.

TABLE 2 RECUPERATOR PERFORMANCE

Week Beginning	Recuperator Utilization		Ave. Boiler Fuel Input	Heat Recovery Rate		
				Total	Average*	Fuel Input
	Hours	%	GJ/h	GJ	GJ/h	%
Oct. 2, 1982	117	69.6	N/A	559	4.78	N/A
9	37	22.0	37.7	156	4.22	11.2
16	94	56.0	N/A	373	3.97	N/A
23	144	85.7	40.0	705	4.90	12.2
30	119	70.8	44.5	566	4.76	10.7
Nov. 6	120	71.4	42.2	502	4.18	9.9
13	113.5	67.6	41.0	550	4.85	11.8
20	167.5	99.7	43.2	778	4.64	10.8
27	168	100.0	41.7	701	4.17	10.0
Dec. 4	150	89.3	42.4	647	4.31	10.2
11	108	64.3	49.4	559	5.18	10.5
18	150.5	89.6	42.4	507	3.37	7.9
25	145	86.3	35.3	468	3.23	9.1
Jan. 1, 1983	168	100.0	41.3	702	4.18	10.1
8	140	83.3	51.9	535	3.82	7.4
15	168	100.0	47.2	759	4.52	9.6
22	168	100.0	45.7	838	4.99	10.9
29	166.5	99.0	44.3	858	5.15	11.6
Feb. 5	168	100.0	42.3	794	4.73	11.2
12	160	95.0	40.3	836	5.23	13.0
19	168	100.0	40.8	839	4.99	12.2
26	168	100.0	38.0	727	4.33	11.4
Mar. 5	162	96.4	41.8	675	4.17	10.0
12	168	100.0	38.6	655	3.90	10.1
19	166	98.8	40.8	664	4.00	9.8
26	168	100.0	35.7	536	3.19	8.9
	3,772	86.4	42.0	16,489	4.38	10.4

* Total divided by recuperator operating hours.

5.3 REDUCTION IN STEAM AND FUEL USE

Table 3 shows that 626,000 m^3 of natural gas were saved in the first six month monitoring period. In order to arrive at this estimate the following factors were applied to the gross heat recovered:

5.3.1 CORRECTION FOR OUTDOOR STORAGE TANK LOSSES

A portion of the water heated by the recuperator on the night shift and on weekends is stored in a 21,200 m^3 outdoor tank. It has been estimated that 10% of the weekly heat recovered is lost due to the heat losses in the tank. Therefore the net heat recovered has been calculated to be 90% of the gross.

5.3.2 STEAM SAVINGS FACTOR

The net heat recovered replaces heat which would otherwise have been obtained from steam. As shown in Appendix A, an average of 0.5198 t of steam are saved for every gigajoule of heat recovered. Therefore the steam saving is obtained by applying the factor to the net heat recovered.

5.3.3 FUEL TO STEAM RATIO

The fuel savings depend on the steam savings and the efficiency of the boilers. The boiler efficiency can be accurately taken into account by using the fuel to steam ratio. The ratio is calculated each week from the metered fuel and steam consumption data and applied to the steam savings to obtain the fuel savings.

TABLE 3 REDUCTION IN STEAM AND FUEL USE

Week Beginning	Gross Heat Recovered GJ	Outdoor Storage Loss Factor	Net Heat Recovered GJ	Steam Savings Factor t/GJ	Steam Savings t	Fuel To Steam Ratio m^3/t	Fuel Savings m^3
Oct. 2, 1982	559	0.9	503	0.5198	262	80.8	21,200
9	156	0.9	140	0.5198	73	80.8	5,900
16	373	0.9	336	0.5198	175	80.8	14,100
23	705	0.9	635	0.5198	330	81.1	26,800
30	566	0.9	509	0.5198	265	81.1	21,500
Nov. 6	502	0.9	452	0.5198	235	81.1	19,100
13	550	0.9	495	0.5198	257	81.1	20,800
20	778	0.9	700	0.5198	364	81.1	29,500
27	701	0.9	631	0.5198	328	82.7	27,100
Dec. 4	647	0.9	582	0.5198	303	82.7	25,000
11	559	0.9	503	0.5198	262	82.7	21,700
18	507	0.9	456	0.5198	237	80.6	19,100
25	468	0.9	421	0.5198	219	81.0	17,700
Jan. 1, 1983	702	0.9	632	0.5198	329	83.3	27,400
8	535	0.9	482	0.5198	251	81.3	20,400
15	759	0.9	683	0.5198	355	83.5	29,600
22	838	0.9	754	0.5198	392	82.6	32,400
29	858	0.9	772	0.5198	401	81.4	32,600
Feb. 5	794	0.9	715	0.5198	372	78.1	29,100
12	836	0.9	752	0.5198	391	82.8	32,400
19	839	0.9	755	0.5198	393	82.8	32,600
26	727	0.9	654	0.5198	340	77.5	26,300
Mar. 5	675	0.9	608	0.5198	316	78.5	24,800
12	655	0.9	590	0.5198	307	77.1	23,700
19	664	0.9	598	0.5198	311	80.9	25,200
26	536	0.9	482	0.5198	251	79.7	20,000
					7,719		626,000

5.4 ENERGY FOR AUXILIARY EQUIPMENT

The heat recovery system contains 82.9 kV·A of auxiliaries. The recuperator normally operates 24 hours per day, therefore the peak demand for power has increased by 82.9 kV·A.

The recuperator operated for 3772 hours during the monitoring period at an estimated power factor of 90 percent.

Therefore the energy consumption was:

$$\begin{aligned} \text{Energy} &= 82.9 \text{ kV·A} \times 3772 \text{ h} \times 0.9 \text{ W/(V.A)} \\ &= 281{,}429 \text{ kW·h} \\ &= 1{,}013 \text{ GJ} \end{aligned}$$

5.5 PROBLEM AREAS AND SOLUTIONS

5.5.1 FREEZING OF MOISTURE IN PNEUMATIC CONTROLS

Much of the down-time during the early part of the monitoring program was due to seized-up flue gas control dampers. This was caused by the freezing of moisture in the pneumatic controls during periods of cold weather. The problem was solved by installing an air dryer to remove moisture from the compressed air in the control system.

5.5.2 CORROSION OF RECUPERATOR CIRCULATING PUMPS

The water re-circulation pumps provided with the recuperator had been expected to be able to withstand acidic solutions. As it turned out, all four pumps were badly damaged by corrosion and had to be replaced after four months of operation. John Thurley Ltd. will provide stainless steel pumps, which should prevent a future recurrence of this problem.

6.0 ECONOMIC ANALYSIS

6.1 CAPITAL COST

The capital cost of the project was as follows:

Item	Cost
Recuperator and Controls	$225,000
Installation and Auxiliaries	175,275
Total Installed Cost	$400,275

6.2 NET ANNUAL SAVINGS

The net annual savings are calculated below:

Fuel Savings	$157,168
Less Cost of Electricity for Auxiliary Equipment	(11,744)
Less Cost of Maintenance	(4,340)
Net	$141,084

The components of the above calculation are explained in the following three sections.

6.2.1 FUEL SAVINGS

During the six month monitoring period of October 1982 to March 1983, the fuel savings were estimated to be $89,810, as shown in Table 4.

It is expected that during the following six months, from April 1983 to September 1983, the savings will decrease by 25 percent to $67,358. This is due to the normal 25 percent variation in the plant's steam production, which will result in a corresponding decrease in the amount of heat recovered.

The annualized fuel savings is the sum of the above savings, which is $157,168.

TABLE 4 FUEL SAVINGS

Week Beginning	Fuel Savings m^3	Fuel Price $\$/m^3$	Cost Savings $
October 2, 1982	21,200	0.1448	3,070
9	5,900	0.1448	850
16	14,100	0.1448	2,040
23	26,800	0.1451	3,890
30	21,500	0.1451	3,120
November 6	19,100	0.1451	2,770
13	20,800	0.1451	3,020
20	29,500	0.1451	4,280
27	27,100	0.1476	4,000
December 4	25,000	0.1476	3,690
11	21,700	0.1476	3,200
18	19,100	0.1476	2,820
25	17,700	0.1476	2,610
January 1, 1983	27,400	0.1416	3,880
8	20,400	0.1416	2,890
15	29,600	0.1416	4,190
22	32,400	0.1416	4,590
29	32,600	0.1416	4,620
February 5	29,100	0.1416	4,120
12	32,400	0.1416	4,590
19	32,600	0.1416	4,620
26	26,300	0.1416	3,720
March 5	24,800	0.1412	3,500
12	23,700	0.1412	3,350
19	25,200	0.1412	3,560
26	20,000	0.1412	2,820
	626,000		89,810

6.2.2 COST OF ELECTRICITY FOR AUXILIARY EQUIPMENT

In section 4.4 it was stated that the recuperator's auxiliaries consumed 1,013 GJ of power at the rate of 82.9 kV•A, during the six month monitoring period. The annualized cost of this power is calculated below:

Energy: 2 x 1,013 GJ x 3.453 $/GJ = $6,996

Demand: 82.9 kV•A x 12 months x 4.773 $/kV•A-Mo. = 4,748

TOTAL $11,744

6.2.3 COST OF MAINTENANCE

The following annual maintenance costs have been projected:

Item	Cost
1. General preventative maintenance	$1,040
2. Annual Shutdown	1,500
3. Instrumentation calibration	800
4. Miscellaneous repairs	1,000
TOTAL	$4,340

6.3 SIMPLE PAYBACK

Based on the capital cost of $400,275 and net annual savings of $141,084, the simple payback of the recuperator is:

$$\frac{\$400,275}{141,084\ \$/yr.} = 2.84 \text{ years}$$

7.0 CONCLUSIONS

The Thurley Direct Contact Heat Recuperator installed at the Winnipeg Packinghouse Plant is recovering the expected amount of heat and has operated without major problems since it was installed in the summer of 1982. Canada Packers is confident that the project will achieve the projected return on investment.

Technically, the recuperator can be applied wherever there is a sufficient balance between steam production and the requirement for low grade heat, such as hot water below 60°C.

The economic viability of the recuperator is largely dependent on the price of fuel. The decision to install one should be based on the payback period of the extra investment over that of a conventional heat recovery system.

APPENDIX A

STEAM SAVINGS FACTOR

A1.0 DERIVATION OF STEAM SAVINGS FACTOR

The heat recovered by the recuperator replaces heat which would have been derived from steam. The reduction in steam consumption can be expressed by:

$$\Delta M_{sr} = K \cdot Q_r \qquad (1)$$

Where: Q_r = heat recovered, GJ (metered)

K = steam savings factor, KG/GJ

ΔM_{sr} = steam saved by recuperator, KG

In order to use equation 1 it is necessary to find an expression for the steam savings factor, K. In order to derive K, it is necessary to consider the change in the water heating process due to the recuperator.

Prior to installation of the recuperator, water was heated by steam injection. The recuperator pre-heats the water to 50°C, which is then heated to the desired temperature by steam injection. Therefore, the recuperator saves steam as follows:

1. It saves some of the live steam used to heat water.
2. It saves the steam used by the de-aerator to heat the make-up for the steam saved in the above item.

The steam saved by the water heating process can be expressed as:

$$\Delta M_{sw} = \frac{M_{hw} \cdot C\ (T_{hw} - T_{cw})}{E_{hw}\ (H_s - C \cdot T_{cw})} \qquad (2)$$

Where: M_{hw} = mass of water heated, KG

T_{hw} = temperature of preheated water leaving the recuperator, °C.

T_{cw} = temperature of cold water entering the recuperator, °C

E_{hw} = efficiency of steam utilization by steam injection water heater

H_s = total enthalpy of steam, KJ/KG

C = specific heat of water, J KG^{-1} K^{-1}

The steam saved by the de-aerator to heat the make-up for ΔMsw can be expressed as:

$$\Delta M_{smu} = \frac{\Delta M_{sw} \cdot C(T_{fw} - T_{mu})}{E_{mu}\,(H_s - C \cdot T_{fw})} \qquad (3)$$

Where: T_{fw} = temperature of feedwater leaving the de-aerator, °C.

T_{mu} = temperature of make-up entering de-aerator, °C.

E_{mu} = efficiency of steam utilization by de-aerator

H_s and C are the same as for equation (2)

The total steam saving is the sum of equations 2 and 3:

$$\Delta M_{sr} = \Delta M_{sw} + \Delta M_{smu} \qquad (4)$$

Substituting equation 3 for ΔMsmu above yields:

$$\Delta M_{sr} = \Delta M_{sw} + \frac{\Delta M_{sw} \cdot C(T_{fw} - T_{mu})}{E_{mu}\,(H_s - C \cdot T_{fw})} \qquad (5)$$

Factoring out ΔM_{sw} yields:

$$\Delta M_{sr} = \Delta M_{sw} \left[1 + \frac{C \cdot (T_{fw} - T_{mu})}{E_{mu}\,(H_s - C \cdot T_{fw})}\right] \qquad (6)$$

Substituting equation 2 for ΔM_{sw} above yields:

$$\Delta M_{sr} = \frac{M_{hw} \cdot C\ (T_{hw} - T_{cw})}{E_{hw}\ (H_s - C \cdot T_{cw})} \left[1 + \frac{C \cdot (T_{fw} - T_{mu})}{E_{mu}\ (H_s - C \cdot T_{fw})} \right] \qquad (7)$$

At this point it is useful to restate the objective. That is, to find K for:

$$\Delta M_{sr} = K \cdot Q_r \qquad (1)$$

Equation 7 (which is equal to equation 1) contains the following term which is equal to Q_r :

$$Q_r = M_{hw} \cdot C\ (T_{hw} - T_{cw}) \qquad (8)$$

This term can be divided out to yield the expression for K:

$$K = \frac{1}{E_{hw}\ (H_s - C \cdot T_{cw})} \left[1 + \frac{C \cdot (T_{fw} - T_{mu})}{E_{mu}\ (H_s - C \cdot T_{fw})} \right] \qquad (9)$$

A2.0 CALCULATION OF STEAM SAVINGS FACTOR

The numerical value of the steam savings factor, K, used in Table 3 was calculated using equation 9, and the following data and assumptions:

DATA: $C = 4.187 \text{ KJ KG}^{-1} \text{ K}^{-1}$

$H_s = 2780.8$ KJ/KG (at steam pressure of 997.6 KPa, ABS)

$T_{cw} = 23.9°C$ (average)

$T_{fw} = 115°C$

$T_{mu} = 23.9°C$ (average)

Assumptions: $E_{hw} = 0.85$

$E_{mu} = 0.90$

$$K = \frac{1}{0.85(2780.8 - 4.187 \times 23.9)} \left[1 + \frac{4.187(115 - 23.9)}{0.90(2780.8 - 4.187 \times 115)} \right]$$

$= 0.0005198$ KG/KJ

$= 0.5198$ t/GJ